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ACQUISITION OF MATCHING-TO-SAMPLE PERFORMANCE IN RATS USING VISUAL STIMULI ON NOSE KEYS

IVER H. IVERSEN

UNIVERSITY OF NORTH FLORIDA

Steady and blinking white lights were projected on three nose keys arranged horizontally on one wall. The procedure was a conditional discrimination with a sample stimulus presented on the middle key and comparison stimuli on the side keys. Three rats acquired simultaneous "identity matching." Accuracy reached 80% in about 25 sessions and 90% or higher after about 50 sessions. Acquisition progressed through several stages of repeated errors, alternation between comparison keys from trial to trial, preference of specific keys or stimuli, and a gradual lengthening of strings of consecutive trials with correct responses. An analysis of the acquisition curves for individual trial configurations indicated that the matching-to-sample performance possibly consisted of separate discriminations.

Key words: matching to sample, conditional discrimination, identity matching, nose key, rats

The matching-to-sample procedure is often used in experimental psychology. In a standard matching-to-sample experiment, a red or green sample stimulus is presented on one key and two comparison stimuli, red and green, are presented on two additional keys. With red on the sample key, a response on the red comparison key is reinforced, whereas with green on the sample key, a response on the green comparison key is reinforced. Such matching-to-sample performance can be established easily with pigeons (e.g., Cumming & Berryman, 1965), monkeys (e.g., Jackson & Pegram, 1970), dolphins (e.g., Herman & Thompson, 1982), and goldfish (Goldman & Shapiro, 1979). Lashley (1938) reported an unsuccessful attempt to establish matching-to-sample performance using rats as subjects. With a three-door jumping-stand apparatus, the middle door was always locked and the rats could jump through one of the side doors. On each trial, a cross or a circle was displayed on the middle door, and the same two figures were displayed on the side doors. The subject was required to jump to the side door that displayed the same stimulus as that on the middle door. Two rats were given 200 trials, but neither rat's behavior came under control.

Several tasks designed for studies of so-called short-term memory in the rat are commonly referred to as variants of the (delayed) matching-to-sample procedure. Such tasks have used multiarm mazes (e.g., Bierley, Kesner, & Novak, 1983; Denny, Clos, & Rilling, 1989; Roitblat & Harley, 1988; Roitblat, Harley, & Helweg, 1989; Wible et al., 1986), one-lever go/no-go discrimination procedures (e.g., J. S. Cohen, Escott, & Ricciardi, 1984; J. S. Cohen, Galgan, & Fuerst, 1986; Pontecorvo, 1983; Wallace, Steinert, Scobie, & Spear, 1980), or two-lever procedures with cue lights (Dunnett, 1985; Kirk, White, & McNaughton, 1988; Thomas & Ahlers, 1991; Thomas, Ahlers, & Schrot, 1991; van Haaren & van Hest, 1989; Wallace et al., 1980). A survey of the literature indicates that rats have not been used previously to establish a matching-to-sample performance with an automated procedure similar to that commonly used with pigeons, monkeys, and humans.

The present experiment was a feasibility study to establish the possibility of acquiring simultaneous "identity" matching-to-sample performance in rats. Visual stimuli—steady and blinking lights—were displayed on three horizontally arranged nose keys. The middle key presented the sample, and the two side keys presented the comparison stimuli.

When matching-to-sample performance occurs at a high accuracy, the sample stimulus controls which comparison key the subject presses. Before a high accuracy is reached, however, other sources of control also influence which comparison key is pressed. The data were analyzed to assess the degree to which

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performance was controlled by the comparison stimuli per se (stimulus preference) and by the position of the comparison stimuli (position preference).

At the procedural level, an attempt was made to counteract position and stimulus preferences by increasing the reinforcement opportunity for a response on the alternative comparison. For example, if a subject often responded to the left side key regardless of the stimulus displayed on it, then the proportion of trials with the right side key correct was increased for one or two sessions to counteract the left-key preference.

The data were analyzed in some detail to cast light on the course of acquisition of the matching-to-sample performance. Repeated errors of continued responding to the key on which a response was reinforced last, alternating between side keys from trial to trial, the length of sequences of correct responses, and preference for comparison stimuli and side keys were tracked session by session. In addition, acquisition was analyzed separately for each of the four stimulus configurations that could appear on the three keys.

METHOD

Subjects

Three experimentally naive female Long-Evans hooded rats, approximately 3 months old at the start of the experiment, were maintained in individual cages with water continuously available. The rats were maintained at 85% of their free-feeding body weights throughout the experiment and were fed approximately 1 hr after each daily session.

Apparatus

A chamber (30 cm wide, 25 cm deep, and 25 cm high) made of clear and opaque Plexiglas® was located in a sound-attenuating cubicle with white masking noise and a fan. One opaque wall had a row of three nose keys, each 2 cm in diameter, 15 cm above the grid floor. The middle key was centered on the wall, and each side key was 9 cm from the middle key. Each key required a force of approximately 0.1 N for operation. Standard Noyes 45-mg food pellets were delivered from a Gerbrands G5120 dispenser into a recessed opening, 1 cm above the floor and centered below the middle key. The opening was 3 cm deep and was covered by a hinged flap (5 cm by 6 cm). A 0.5-s "beep" from a Sonalert® (28 VDC with a 20-kohm resistor in series) accompanied each pellet delivery.

Each key could be illuminated from behind by a 14-VDC white light. The stimulus projected on each key was either a steady light or a blinking light (50 ms on, 50 ms off). To a human observer, the blinking light appeared dimmer than the steady light. The present experiment did not determine whether steady versus blinking or bright versus dim controlled the rats' performances. Throughout the experiment, the chamber was dark except for the lights that appeared on the response keys. Programming and recording were accomplished by a Tandy® Model 102 computer.

Procedure

Pretraining. Magazine training consisted of two 40-min sessions with response-independent delivery of food pellets on a variable-time (VT) 2-min schedule. For the next five sessions, each rat was trained to press, with its nose, a side key lit with either a steady or blinking white light. Only one key was lit, and a press on the lit key produced a food pellet and extinguished the light; pressing an unlit key extinguished the lit key without producing a food pellet. Steady or blinking light appeared equally often on the side keys with 10-s intertrial intervals (ITI); pressing an unlit key during the ITI reset the interval. Each session presented 100 trials. Then, for two sessions of 100 trials, the center key was lit with steady or blinking light; a press on the lit center key turned on the same stimulus on one of the side keys while the center key remained lit and the other side key remained unlit. A press on the lit side key produced a food pellet and extinguished both keylights. By the end of pretraining, the subjects pressed the center key within a few seconds after it was lit and then immediately pressed the lit side key; pressing rarely occurred on an unlit key.

Matching-to-sample training. All trials began with the sample appearing on the center key. A press on the sample key produced two comparison stimuli on the side keys while the sample key remained lit. The comparison stimuli were always one steady light and one blinking light. If the sample was the steady light, then pressing the comparison key with

the steady light was considered correct. Similarly, if the sample was the blinking light, then pressing the comparison key with the blinking light was correct. A correct press produced a food pellet and extinguished the lights on all three keys. A press on the comparison with the nonmatching stimulus ended the trial without a food pellet. Pressing an unlit side key after the sample had appeared (before pressing the sample key) or pressing the sample key again after the side keys were lit had no programmed consequences other than being recorded. A press on any key during the ITI reset the interval. The ITI was 3 s throughout the experiment. Each session had a minimum of 100 trials. A correction procedure was in effect for the first 50 sessions for Rats 1 and 2 and for the first 10 sessions for Rat 3. In this procedure, a press on the nonmatching comparison key caused the trial to be repeated after the ITI. A repeated trial was considered an added trial; the total trials for a session therefore depended on how many trials were repeated. In other words, total number of trials in a session was 100 plus the number of repeated trials.

The program arranged for a loop of 120 trials. The trial distribution was such that for each trial, steady and blinking lights were equally likely on the sample key, and the correct comparison could be on the left or right side key with equal probability. However, the same sample stimulus could not be repeated on more than three consecutive trials (given no correction trials), and the same correct key position also could not be repeated on more than three consecutive trials. Each session began at a randomly determined position within the 120-trial loop.

Timeout following a press on the nonmatching comparison. In selected sessions during early training of Rats 1 and 2, a timeout followed an incorrect response (i.e., a press on the nonmatching comparison). The timeout durations were fixed at 10 and 20 s for Rat 1 and 10, 20, and 30 s for Rat 2. The timeout prolonged the ITI. The results and the sessions with timeout are indicated in Figure 1. Timeout was not used for Rat 3.

Correction of stimulus or key preference. In selected sessions during training, the programmed trial sequence was altered to compensate for comparison stimulus or side-key preferences that had developed in prior sessions. For example, if a rat's data had indicated a preference for the left side key (Key 1) for some sessions, then the proportion of trials with the other side key (Key 3) as the correct key was increased for one or more sessions so that two thirds of the trials in a session had the correct comparison on Key 3. Similarly, if a rat's data indicated a preference for the comparison with a steady light, then the trial distribution was changed so that two thirds of the trials in a session had the blinking light on the correct comparison key. Sessions with correction of stimulus or key preference were scheduled for each rat depending on prior performance and are indicated in Figures 1 and 2. The number of sessions with correction of stimulus or key preference was 11, 6, and 5 for Rats 1, 2, and 3, respectively.

Zero-second delay. After the rats had acquired a high accuracy on the matching-to-sample performance, they were shifted to a procedure in which the positions of the sample and the comparison keys were changed within sessions; the results will be reported elsewhere. The rats were later retrained to the regular matching-to-sample procedure, with the sample always appearing on the middle key. A 0-s delay procedure was then scheduled for one session for each rat. A response to the lit sample key produced the two comparison stimuli and turned the sample stimulus off; otherwise the procedure was identical to that during the last stages of acquisition.

RESULTS

All 3 rats acquired matching-to-sample performance with a stable accuracy of 90% correct or better. An accuracy of about 80% was reached within 25 sessions for all rats. Consistent accuracy of 90% or higher was obtained after 50, 60, and 45 sessions for Rats 1, 2, and 3, respectively. The highest accuracy achieved for a given session was 98%, 96%, and 96% for Rats 1, 2, and 3, respectively.

Acquisition proceeded through the same stages for each rat. Figure 1 shows the acquisition data for each session. Data are the percentage correct trials (100 × reinforced trials/all trials), the percentage of trials with an error repeated from the previous trial [100 × repeat errors/(all trials − 1)], the percentage of trials with an alternation from the side key chosen on the previous trial to the other side

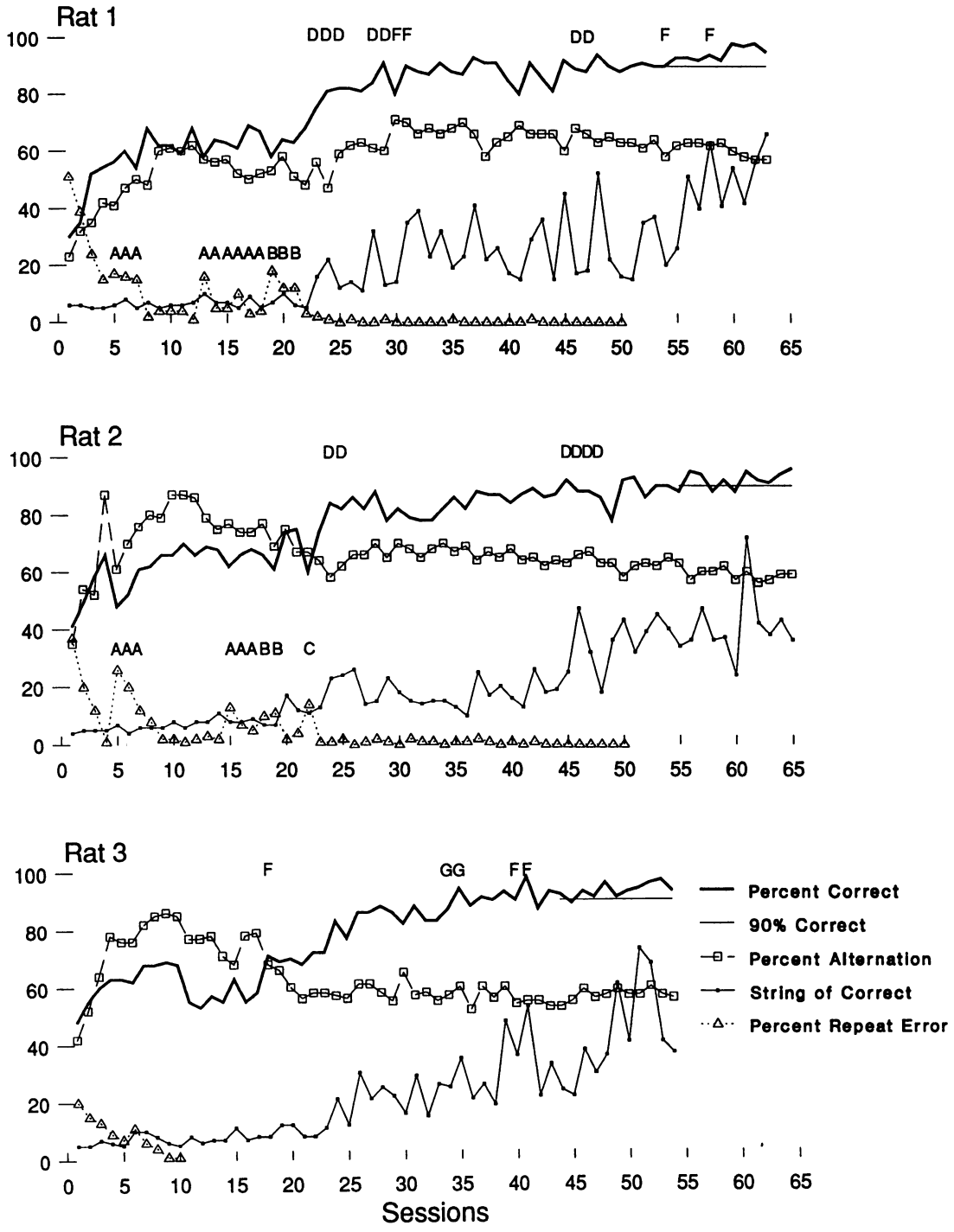

Fig. 1. Acquisition of matching-to-sample performance for each rat. Data show percentage correct, percentage alternation (based on switching from one side key to the other from one trial to the next), and percentage repeat error (based on repeat responses to the same trial configuration after the first error). Also shown is the longest string of consecutive correct trials uninterrupted by errors (the ordinate indicates number of trials for this performance measure). Data are based on all trials presented in a session, except for repeat errors and alternation, which cannot occur on the first trial. The 90% level is indicated for the last 10 sessions for each rat. Letters indicate sessions with the timeout or preference-counteracting procedure in effect. For timeout, A = 10 s, B = 20 s, C = 30 s. For the preference-counteracting procedure, letters indicate which dimension was reinforced more often (D = Key 1, F = blinking light, G = steady light).

key [100 × alternations/(all trials − 1)], and the longest string of consecutive correct trials without interruption by errors. (Note that a repeated error and an alternation cannot occur on the first trial in a session.)

Repeat Errors and Alternation

Accuracy began at below 50% for all rats and increased to about 60% within four to six sessions. The initial reaction of the rats often was to repeat pressing the key on which a press was reinforced last. In the first sessions, the rats made several such repeat errors in a row. For example, in Session 1, the longest string of successive trials with repeat errors was nine, seven, and five for Rats 1, 2, and 3, respectively. The correction procedure ensured that repeat errors were not reinforced and instead selectively reinforced an alternation to the other side key on the next trial following an error. As the percentage of trials with an alternation increased, the percentage of repeat errors decreased, and eventually the repeat errors dropped out. During the course of acquisition, trials with a side-key alternation from the previous trial increased from about 40% to more than 80% and then decreased to below 60% for Rats 2 and 3. For Rat 1, alternation initially increased from near 20% to 60%, then fluctuated, and eventually stabilized at around 60%. (Because of the construction of the programmed trial distribution, a 100% correct matching-to-sample performance entailed a 58% alternation; i.e., the probability that the other side key would be correct on the next trial was slightly higher than was the probability that the same key would be correct on the next trial.)

Timeout

The introduction and removal of timeout following errors for Rats 1 and 2 affected the repeat errors (see sessions marked A, B, or C in Figure 1). Percentage of repeat errors increased and percentage correct decreased each time a timeout was introduced or increased in duration. Figure 1 gives the sessions in which timeout was manipulated for Rats 1 and 2; timeout was not used for Rat 3. The timeout procedure appeared to facilitate or sustain the repeat errors and was therefore abandoned. For example for Rat 2, the first introduction of a 10-s timeout in Session 5 increased the percentage repeat errors from 1 to 26 and decreased the percentage correct from 66% to 48%. After the timeout was removed, the percentage repeat errors decreased quickly to near zero. Because of its effect on the repeat errors, the timeout actually counteracted the intended effect of the correction procedure.

Correction Procedure

The effects of the correction procedure are best illustrated for Rat 3. By Session 10, Rat 3 simply alternated between the side keys from trial to trial for most of the session. The correction procedure was removed in Session 11, and the percentage alternation then decreased when alternating was reinforced less often. Also, the percentage correct dropped from about 66% to about 55% with the removal of the correction procedure. The higher percentage correct before removal of the correction procedure was thus obtained because alternation on the next trial after a trial with an error had always produced reinforcement.

The correction procedure was removed after Session 50 for Rats 1 and 2. Because alternation had stabilized and the accuracy had reached almost 90%, removal of the correction procedure had no effect on the matching-to-sample performance for Rats 1 and 2.

Uninterrupted Strings of Correct Trials

The longest strings of consecutive correct trials were just four to six trials long in the first sessions (see Figure 1). Between Sessions 20 and 25, the number of correct trials in a row began to increase and eventually reached high values. Up to an accuracy of about 80%, the longest strings of correct trials were shorter than 20 trials. No correct strings were longer than 40 trials until accuracy was 90% or higher. The longest strings of correct trials for a given session were 66, 72, and 73 for Rats 1, 2, and 3, respectively. Note that a performance of about 90% correct does not require or force such long strings of correct trials, as seen in the occasional much shorter strings at high accuracy in Figure 1. Consider a hypothetical case with one error for every ninth correct trial. A subject would reach an accuracy of 90%, and the longest string of consecutive correct trials would be only nine trials. The rats' performances were very different. For example, for Rat 2 at Session 57 with 94% correct, the longest string was 47 trials. With C indicating a correct trial and E an error trial, the trial

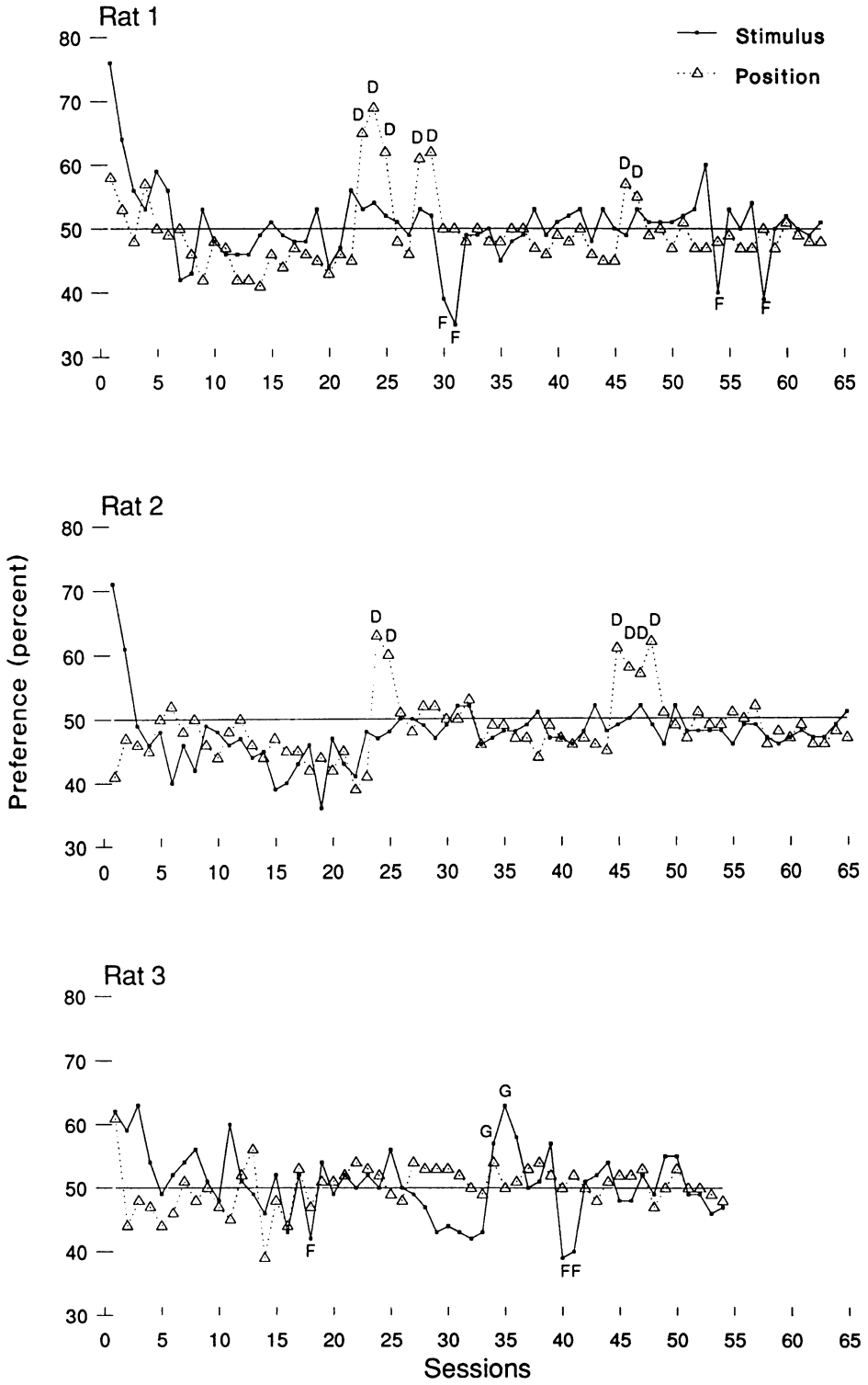

Fig. 2. Position and stimulus preference for each rat and session. Position preference is expressed with respect to Key 1 (left). Scores above 50% indicate preference for Key 1, whereas scores below 50% indicate preference for Key 3. Stimulus preference is expressed with respect to the steady light. Data are based on all trials presented in a session. The 50% level is indicated for each rat. Letters indicate sessions with the preference-counteracting procedure in effect (D = Key 1, F = blinking light, G = steady light).

sequence from the beginning of that session was 1C, 1E, 4C, 1E, 47C, 1E, 6C, 3E, and 36C. Typically the rats developed a pattern of a few very long strings separated by one or a few errors. These data indicate that an increase in percentage correct from 80% to 90% or higher represents a considerable further development in the cohesiveness of the matching-to-sample performance.

Position and Stimulus Preference

Position preference was calculated as the percentage of trials with a press on Key 1, irrespective of outcome. Stimulus preference was calculated as the percentage of trials with a press on the side key with the steady light, irrespective of outcome. Each trial contributed to both preference measures. For position preference, scores above 50% defined control by Key 1, and scores below 50% defined control by Key 3. Similarly, for stimulus preference, scores above 50% defined control by the steady light, and scores below 50% defined control by the blinking light. These data are shown in Figure 2.

Preference for the steady light occurred for all rats for the first two to six sessions. Later, position or stimulus preference built up gradually over sessions. For example, for Rat 1, position preference decreased to below 50% and remained at that level from Session 8 through Session 22. To counteract this control by Key 3, the trial distribution was altered for three sessions so that Key 1 displayed the correct stimulus more often than Key 3 (see Procedure). Sessions with altered trial distributions are indicated in both Figures 1 and 2. As seen in Figure 2 for Rat 1, the procedural change immediately switched the position preference to Key 1. The regular trial distribution was reinstated for the next two sessions, but position preference again fell below 50%. The trial distribution was therefore altered again for two sessions. Preference switched to Key 1, and when the regular trial distribution was reinstated, neither key was preferred for the next 13 sessions. A Key 3 preference then developed for several sessions, and the trial distribution again was changed for two sessions. Position preference was less pronounced for the remaining sessions.

Stimulus preference fluctuated after the first few sessions for Rat 1, but from Session 22 through Session 29, preference for the steady light reappeared. For two sessions the blinking light was made correct more often. This change shifted the stimulus preference in the succeeding sessions. But by Session 53 preference for the steady light reappeared; two additional sessions with altered trial distributions counteracted this preference.

For Rats 2 and 3, sessions with altered trial distributions were scheduled on occasion to generate preference in the opposite direction of what had developed in prior sessions. As for Rat 1, preference was less pronounced following sessions with altered trial distributions.

Considering the data for all rats, temporarily forcing a preference in the direction opposite to that displayed by the subject successfully abolished the position or stimulus preference. In general, when position or stimulus preference was corrected successfully after sessions with altered trial distributions, the percentage correct tended to increase.

Acquisition of Individual Trial Configurations

After a press on the sample key, one of four stimulus configurations appeared on the three keys. Using B for blinking and S for steady light, the configurations were BBS, SBB, SSB, and BSS (each from left to right key). The top row in Figure 3 presents the percentage correct for each trial configuration for the first 35 sessions for each rat. To determine whether matching-to-sample performance was acquired separately for each sample and for each correct comparison key, the second and third rows show data combined for each sample and for each side key correct, respectively.

As indicated earlier, preference for the steady light occurred for all rats in the first few sessions. Hence, the percentage correct was low on BBS and SBB trials and high on SSB and BSS trials. For Rats 1 and 2, the percentage correct on B-sample trials (BBS and SBB) quickly increased, whereas the percentage correct on S-sample trials (SSB and BSS) did not change consistently. The percentage correct on SBB exceeded that on BBS trials from Session 5 through Session 23 for Rat 1 and from Session 13 through Session 24 for Rat 2. For Rat 1, the percentage correct fluctuated on S-sample trials up to Session 22, with no clear separation between the acquisition curves. After Session 22, the percentage correct improved quickly for SSB trials and gradually for BSS trials. For Rat 2, the percentage correct on

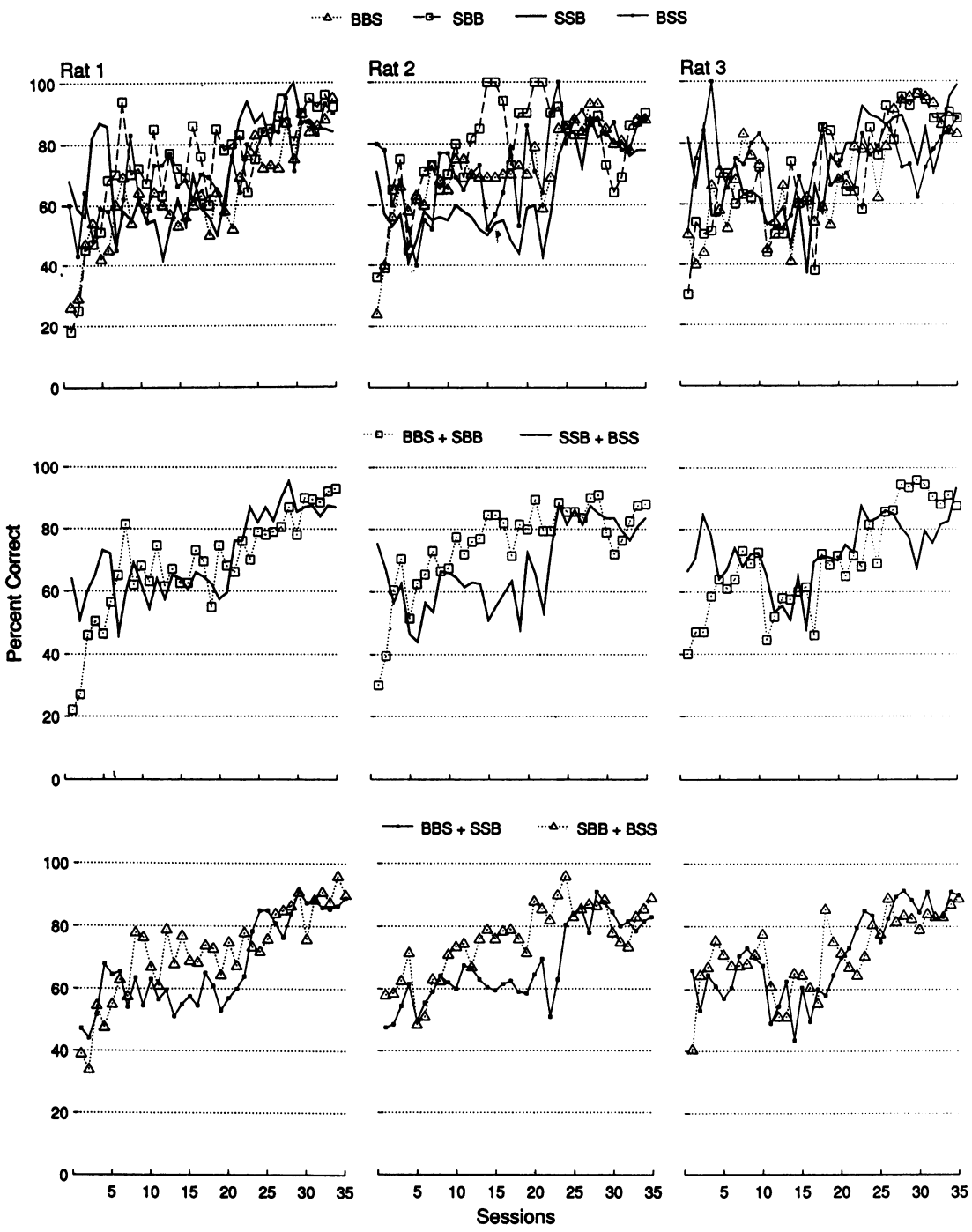

Fig. 3. Acquisition (percentage correct) analyzed for each trial configuration and for pairs of configurations for the first 35 sessions for each rat. (S = steady light, B = blinking light.) The top row shows data for each trial configuration. The second row shows data combined for each sample. The third row shows data combined for each side key correct. To facilitate comparison of the curves, the horizontal grids show percentages in jumps of 20.

SSB trials remained below 60% (except for the first session) up to Session 23 and then jumped to about 80% for the remaining sessions; the percentage correct on BSS was consistently higher than on SBB trials but fluctuated, and the acquisition was more gradual. The data for Rats 1 and 2 indicate that acquisition proceeded somewhat differently for the different trial types. Overall, the fastest acquisition occurred for SBB trials and the slowest occurred for SSB trials.

For Rat 3, the percentage correct fluctuated considerably, and the individual acquisition curves are not easily separated, except after Session 27 with SSB and especially BSS trials falling considerably below 80%.

Separate acquisition is seen more easily when the trial configurations are combined for common sample and common correct key. For Rat 1, and especially for Rat 2, the acquisition for B-sample trials progressed faster than for S-sample trials. Percentage correct increased gradually on B-sample trials but increased abruptly on S-sample trials. When analyzed for correct side key, acquisition progressed faster for the right side key than for the left side key for Rats 1 and 2. Again, for Rat 3, the acquisition curves are difficult to separate, except after Session 27 where the percentage correct was higher for the B-sample than for the S-sample trials.

Zero-Second Delay

On the last three sessions before the one session with a 0-s delay between sample and comparisons, the overall percentage correct was 97%, 95%, and 96% for Rats 1, 2, and 3, respectively. Table 1 presents the percentage correct for each trial configuration during the single 0-s delay session. Note that the trial configurations were sequential: The sample appeared first and disappeared when the comparison stimuli appeared on the side keys.

For Rat 1, the sample control transferred to the 0-s delay condition for all trial configurations, except for a small decline in accuracy on S(S)B trials. For Rat 2, the percentage correct remained high for B-sample trials but dropped to near 50% for S-sample trials. For Rat 3, the percentage correct dropped considerably on B(S)S trials and dropped to some extent on S(S)B trials. The breakdown in the matching-to-sample performance for Rats 2 and 3 with the 0-s delay was thus specific to the steady sample. For Rats 2 and 3, even after high accuracy had been obtained, the 0-s delay brought back the trends from prior sessions. For Rat 2, S-sample control had been acquired more slowly than B-sample control (middle row in Figure 3), and the S sample lost control during the 0-s delay session. For Rat 3, the BSS trial configuration had been the last to reach high accuracy (first row in Figure 3), and the accuracy dropped considerably for this configuration with the 0-s delay. The 0-s delay data are thus congruent with the acquisition data.

Table 1

Percentage correct for each trial configuration and for all trial configurations together during one session with a 0-s delay in the matching-to-sample procedure. A response to the sample turned it off and lit the side keys. Letters in parentheses indicate the sample stimulus.

Subject	All trials	B(B)S	S(B)B	S(S)B	B(S)S
Rat 1	94	96	96	88	95
Rat 2	75	100	96	42	66
Rat 3	78	100	96	85	26

DISCUSSION

Matching-to-sample performance with visual stimuli was established successfully in rats with a procedure similar to that commonly used with other nonhuman subjects. An accuracy of about 80% was achieved within 25 sessions (≥2,500 trials), and an accuracy of 90% or better was reached after about 50 sessions. How do rats compare to pigeons? Pigeons can acquire simultaneous matching-to-sample performance considerably faster than the rats did in the present experiment. For example, in one study by Rodewald (1974), 3 pigeons acquired red, green, and yellow matching at above 90% accuracy in just three sessions. Species comparisons are difficult, however, when in the same species (i.e., pigeons) speed of acquisition depends critically on stimulus features (e.g., Carter & Eckerman, 1975) and on a host of other procedural variables (see Mackay, 1991).

A correction procedure was used in the present experiment because it is known to facilitate the acquisition of matching-to-sample performance by abolishing position and stimulus preferences (Mackay, 1991). Without a cor-

rection procedure, a consistent position or stimulus preference may be maintained by intermittent reinforcement. That is, a subject may always press a specific comparison key, and this response will be reinforced on an average of every other trial. With a correction procedure, a given trial is repeated after an error until the subject switches to the other comparison key. Thus, the correction procedure selectively reinforces alternation after errors. In the present experiment, Rat 3 often alternated between the side keys by Session 10. The percentage of trials with alternation quickly decreased after the correction procedure was removed. Albeit tentative, the present results suggest that the correction procedure can promote alternation to an extent that may interfere with acquisition of matching-to-sample performance. Conceivably, matching-to-sample performance might develop faster if the correction procedure were to be removed as soon as alternation between the side keys begins to occur reliably.

In the present experiment, control by comparison stimuli and key position was counteracted in selected sessions by altering the trial distribution so that a response to the opposite comparison stimulus or key would become more likely to be reinforced. This preference-counteracting procedure was scheduled depending on an individual subject's performance over sessions. All in all, control by stimuli and key position was very likely to disappear after this procedure had been used for one or two sessions.

Strong stimulus preference in initial sessions means that a subject responds differentially to the stimuli (i.e., the subject discriminates the stimuli). When hue stimuli are used with pigeons, strong stimulus preferences are apparent in the early training sessions, but when vertical and horizontal stimuli are used, stimulus preferences are not apparent early in training (Carter & Eckerman, 1975). That pigeons acquire matching-to-sample performance considerably faster with hue stimuli than with line stimuli may reflect a difference in discriminability of the stimuli. Several sessions may be required to establish a discrimination that does not exist when an experiment begins.

In the present experiment, the strong preference for the comparison stimulus with the steady light in the first few sessions for all 3 rats indicates that the steady and blinking lights were in fact discriminable from the outset of the experiment. Therefore, acquisition of matching-to-sample performance did not take 50 sessions because the rats had to acquire the discrimination. In addition to the control by the sample stimuli that eventually came about, the matching-to-sample procedure also generated response patterns that were unwanted (from the experimenter's perspective). The acquisition of matching-to-sample performance came about as the unwanted response patterns were eliminated.

Considering the present results collectively, the rats did not begin the acquisition of matching-to-sample performance by chance responding. In the first sessions, reinforcement simply made the subjects press the same key on which a press had just been reinforced (the repeated errors); this is consistent with long-known perseverative effects of reinforcement (Iversen, 1992). Next, reinforcement consistently followed alternation after an incorrect response (because of the correction procedure) and therefore facilitated alternation between side keys. After repeated errors had vanished and alternation had stabilized, comparison stimuli and key positions controlled performance. When stimulus and key preferences were counteracted procedurally, matching-to-sample performance quickly reached high accuracy. The present results suggest that some of these performance patterns might be directly manipulated to facilitate the acquisition of matching to sample in rats.

Customarily the "strength" of matching-to-sample performance is indicated by accuracy or percentage correct. A criterion of performance near 80% correct often is considered sufficient as an indicator of satisfactory acquisition of matching to sample. In the present experiment, an additional indicator of performance was the length of strings of correct trials without interruption. For all rats, a change in overall accuracy from about 80% to 90% or higher was associated with a considerable further lengthening of strings of correct trials.

Because of the small number of long strings of consecutive correct trials during each session with high accuracy, the average string length per session appears to be an inappropriate measure of performance. However, the longest string was quite informative, in spite of the apparent session-to-session variability (Figure 1). Obviously, at very high accuracy, the lon-

gest string cannot be shorter than a certain minimum. For example, at 98% correct, the longest string of correct trials cannot be shorter than 33 trials; at 97%, it cannot be shorter than 25 trials, and at 96%, it cannot be shorter than 20 trials. The results indicate that matching-to-sample performance may not be fully developed even when the overall accuracy is near 80% correct. The cohesiveness of the performance, as represented by the length of strings of consecutive correct trials, holds promise as an additional analysis of matching-to-sample performance.

Finally, the present data suggest that acquisition may not proceed at the same rate for individual trial configurations. Rather, some trial configurations were acquired faster than others, and in some instances acquisition for a given trial configuration was very sudden after many sessions with near chance performance. For Rat 2 in particular, acquisition proceeded differently for the two sample stimuli. And, for Rats 1 and 2, acquisition depended on which side key displayed the correct stimulus; percentage correct was consistently higher for Key 3 than for Key 1 for 15 and 12 consecutive sessions for Rats 1 and 2, respectively.

Some previous analyses of matching-to-sample performance in pigeons and monkeys have suggested that subjects may respond differentially to specific stimuli rather than acquire a "matching concept." For example, Kamil and Sacks (1972), using two hue stimuli (red and green) with pigeons, presented three of four possible trial configurations in training (RRG, GRR, and RGG). Acquisition proceeded differently for each configuration. When a high accuracy had been reached, the fourth configuration (GGR) was mixed in with the trained configurations. No positive transfer occurred to the new configuration. Kamil and Sacks suggested that control of the subjects' behavior had been acquired by each configuration separately. In addition, the position preference that had occurred early in training of the three configurations reappeared when the fourth configuration was introduced. In an experiment by Sidman (1992), a five-key arrangement was used with monkeys as subjects. The sample appeared on the center key, and two comparison stimuli appeared on pairs of the four outer keys. Separate acquisition curves were obtained for the six different pairs of comparison keys. After performance had reached high accuracy, the probability of reinforcement was reduced. Performance deteriorated differently for each key pair with a return of control by key position, which had been observed during training. Sidman concluded that the subjects had acquired six separate conditional discriminations, one for each key pair.

The results of the present experiment confirm the results of Kamil and Sacks (1972) and Sidman (1992). Separate acquisition curves were evident for different trial configurations. In addition, when a 0-s delay was introduced in one session, the breakdown in performance for 2 rats stemmed from a return to response patterns seen earlier in acquisition. Apparently, the rats had merely acquired a discrimination of specific stimuli and their position. The collective data support the growing evidence from studies with pigeons and monkeys that subjects do not ordinarily acquire a "matching concept" but instead acquire separate discriminations (see also L. R. Cohen, Looney, Brady, & Aucella, 1976; D'Amato & Colombo, 1989; Farthing & Opuda, 1974; Holmes, 1979; Iversen, Sidman, & Carrigan, 1986; Santi, 1978).

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